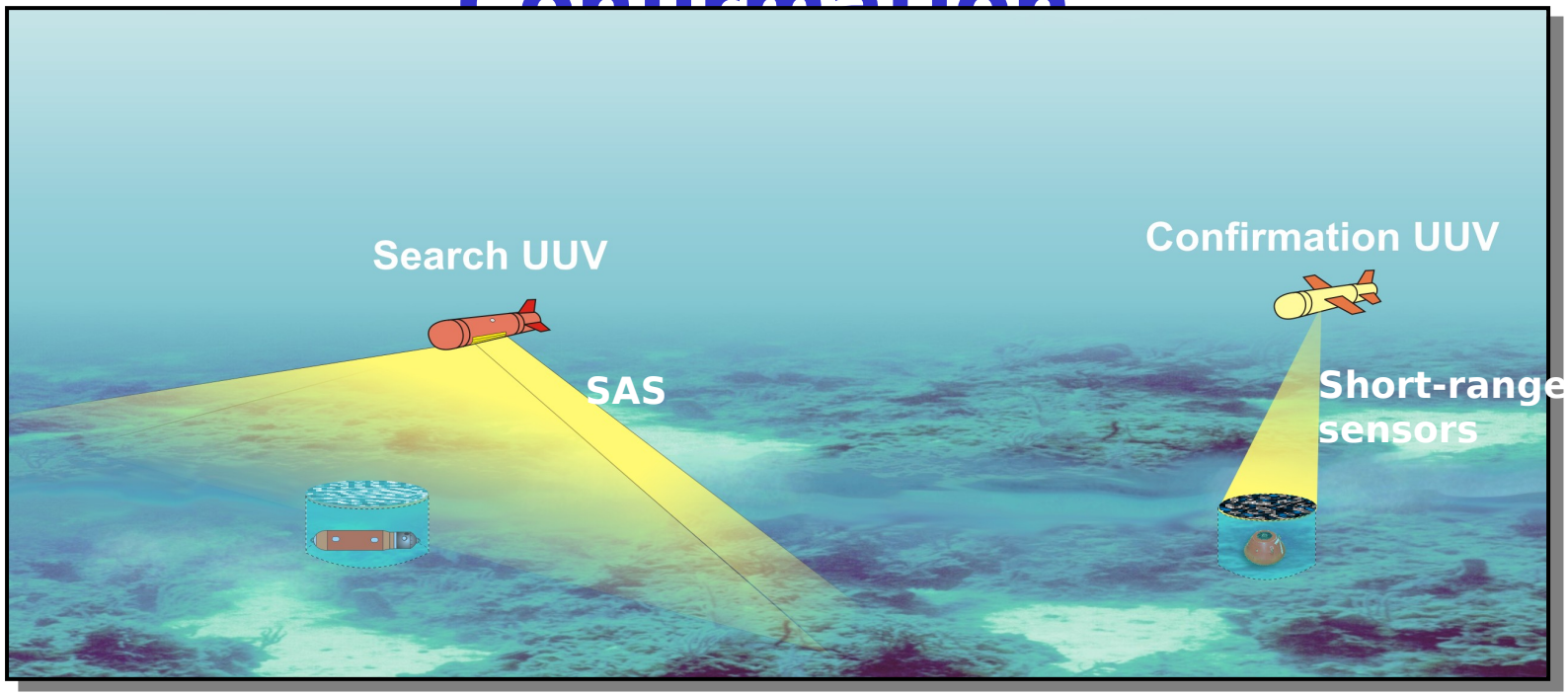
Technology Insertion for SMCM UUV

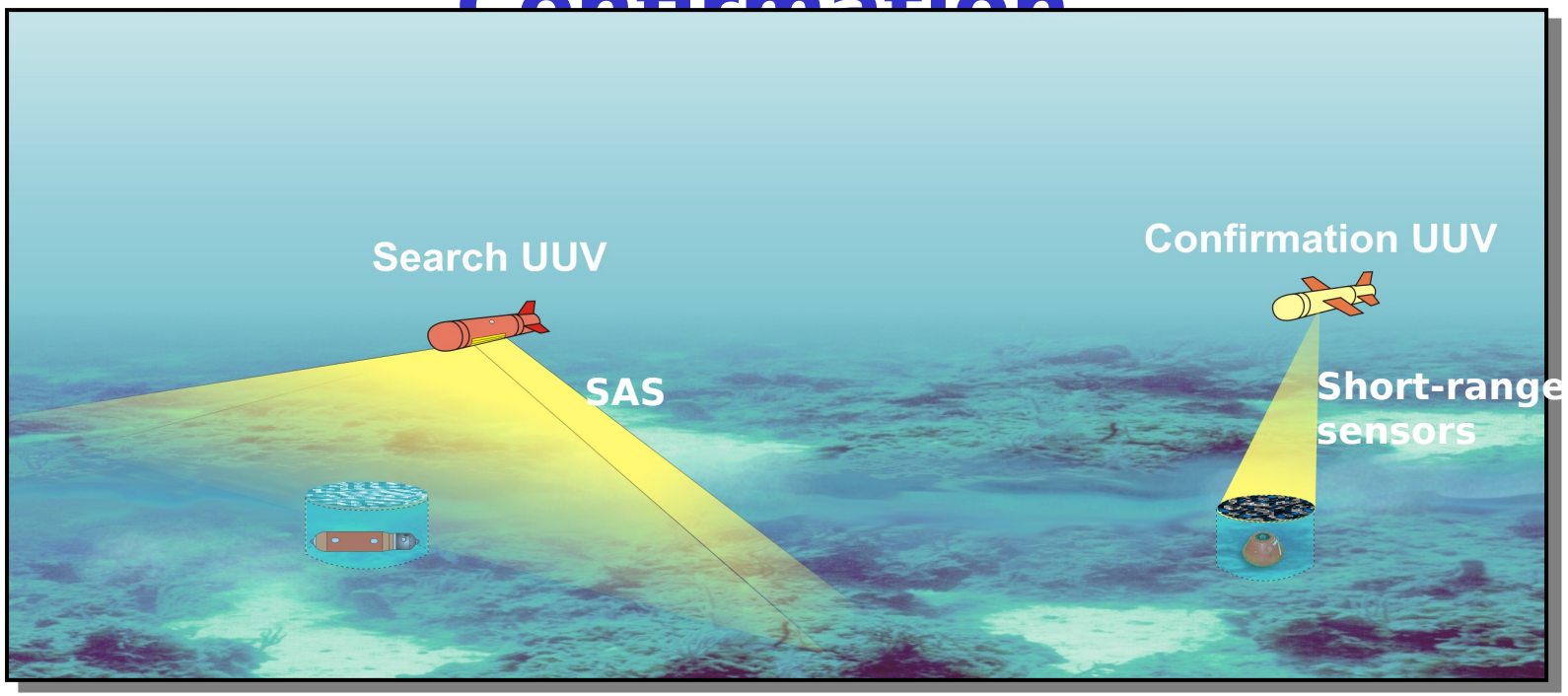
- ONR's Concept for Minehunting from UUV's
- Acoustic Classification of Mines
- The Physical Acoustics of Buried Mine Hunting

ONR's Notional MCM Concept: Synchronous UUV Search and Confirmation



- **Search SAS detects and classifies minelike targets in real time**
- **Short-range confirmation sensors identify the minelike targets**
  - **Candidate confirmation sensors: Bottom Object Scanning**

ONR's Notional MCM Concept: Synchronous UUV Search and Confirmation



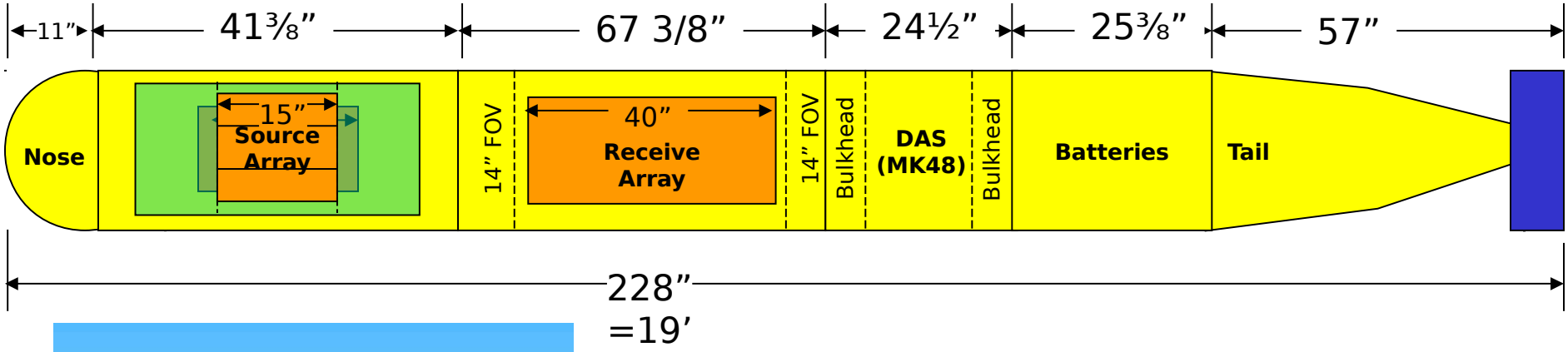
FY 2002 – 2005: **Develop and leverage component technologies**

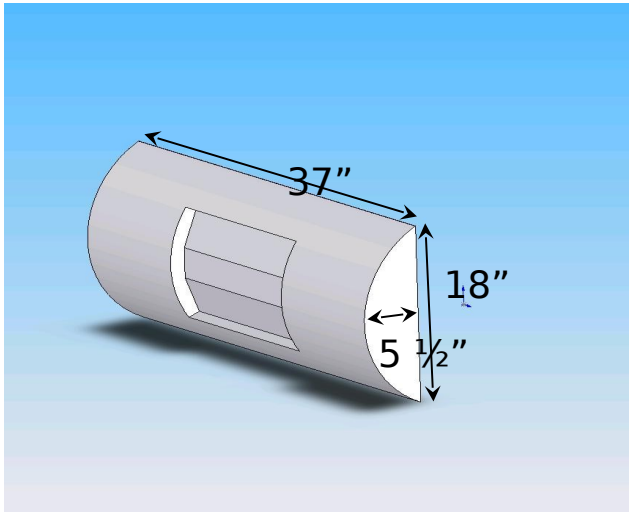
FY 2005 – 2007: **Conduct at-sea tests of integrated sensor system prototypes**

FY 2007: **Final demonstration of optimized**

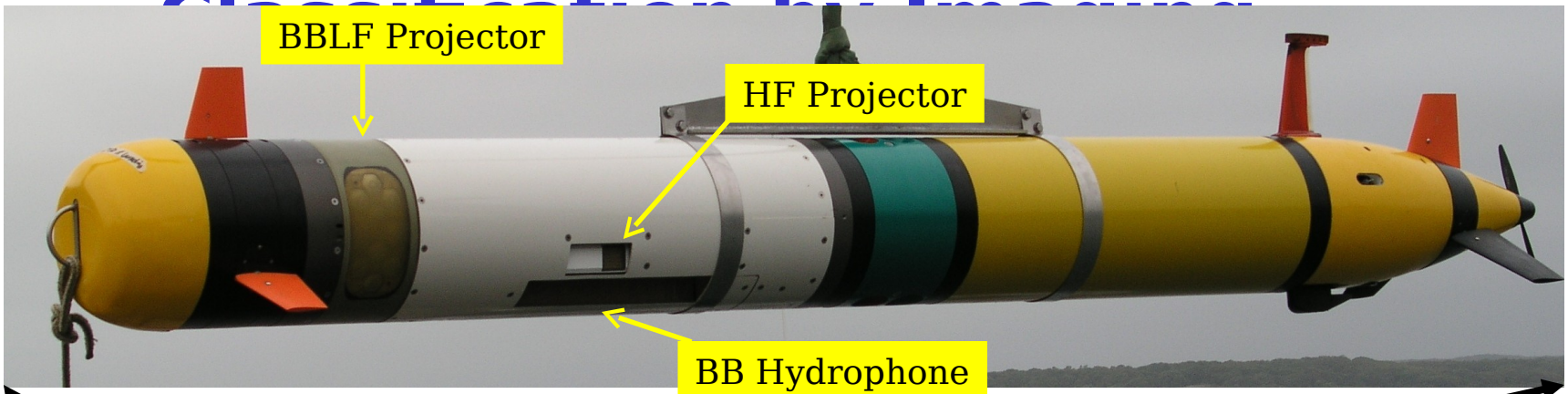
Examples of Search UUV SAS Candidates

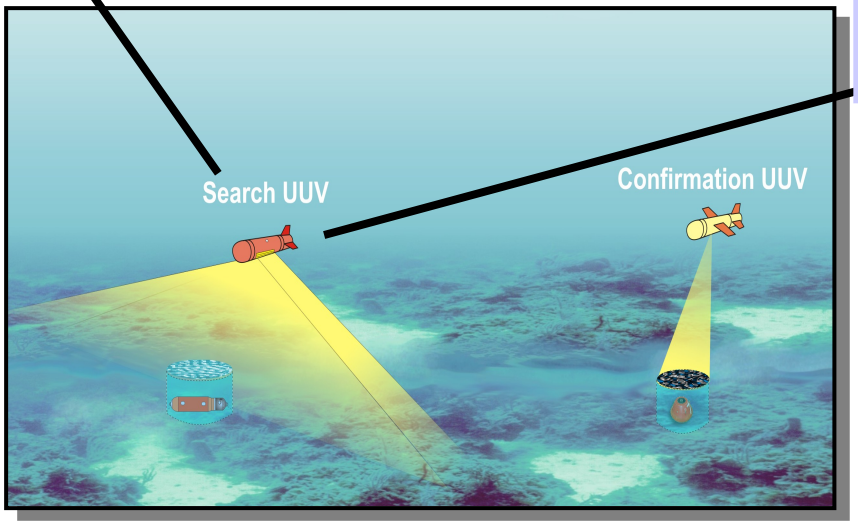
Low Frequency Broadband (LFBB) SAS: Classification by Acoustic Color



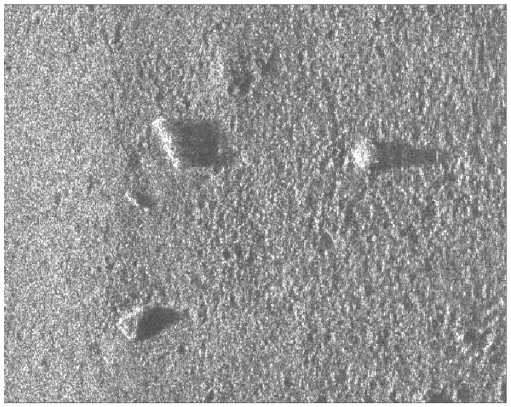


Small Synthetic Aperture Minehunter (SSAM): Classification by Imaging

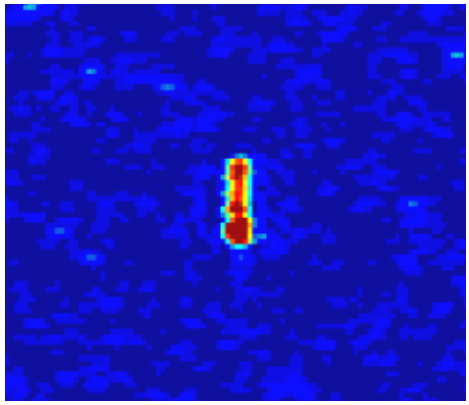




HF Band: 105 kHz-135 kHz
1” x 1” resolution



LF Band: 10 kHz–52 kHz
3 ”x 3” resolution



SAS Can Provide Much Higher Performance than RAS for AUV's

- **Big AUV example: L_{array} = 6 ft, res = 1", v = 4 kt**

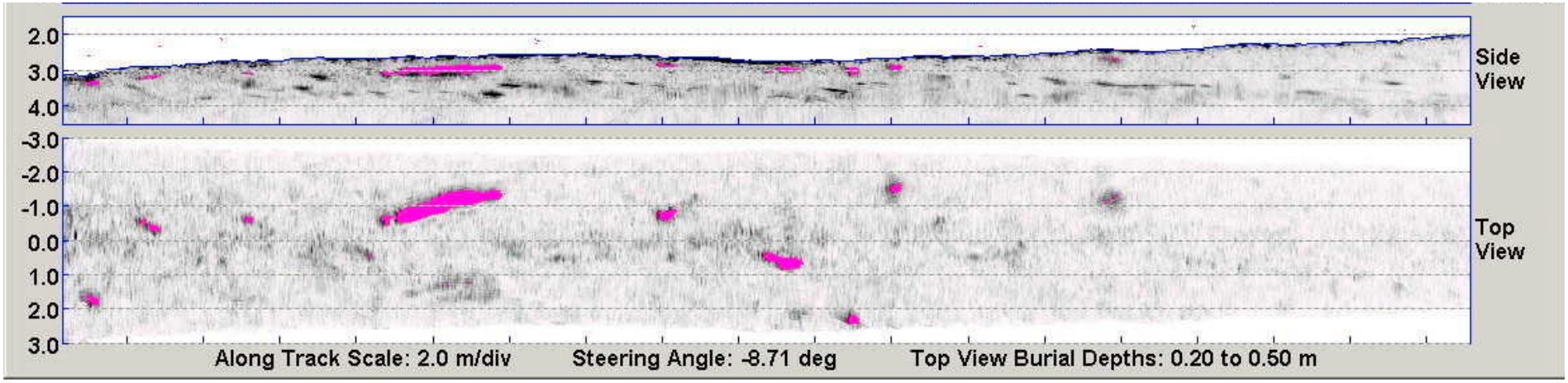
	Elements per Side	Operating Frequency	Maximum Range	Area Coverage Rate
RAS	72	900 kHz	Ld/λ = 90 ft	0.12 nmi²/hr
SAS	36	60 kHz < f < 120 kHz	Lc/4v = 1100 ft	1.4 nmi²/hr

- **Small AUV example: L_{array} = 1 ft, res = 1", v = 4 kt**

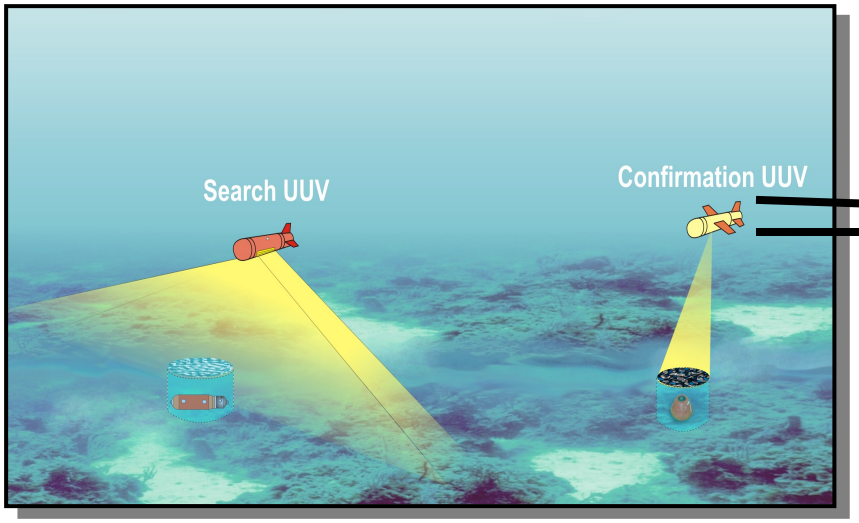
	Elements per Side	Operating Frequency	Maximum Range	Area Coverage Rate
RAS	12	2.0 MHz	Ld/λ = 33 ft	0.04 nmi²/hr
SAS	6	60 kHz < f < 700 kHz	Lc/4v = 180 ft	0.24 nmi²/hr

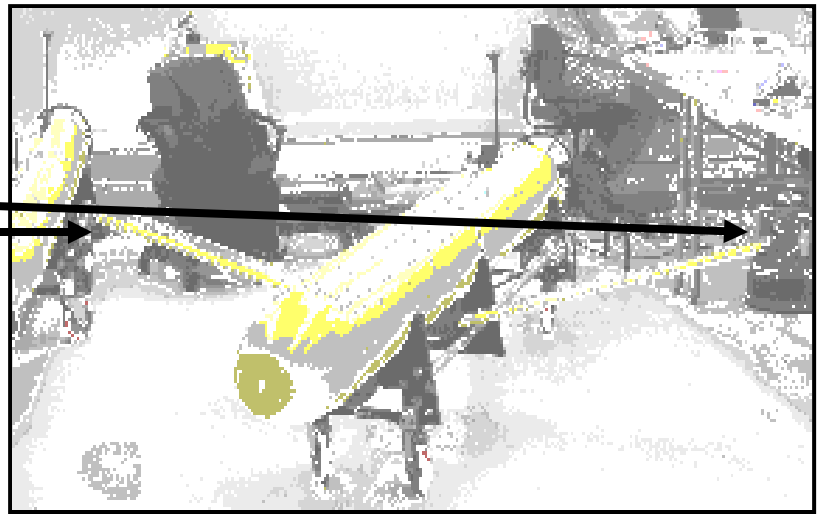
Examples of Confirmation UUV Sensor Candidates

Bottom Object Scanning Sonar (Short-Range SAS)



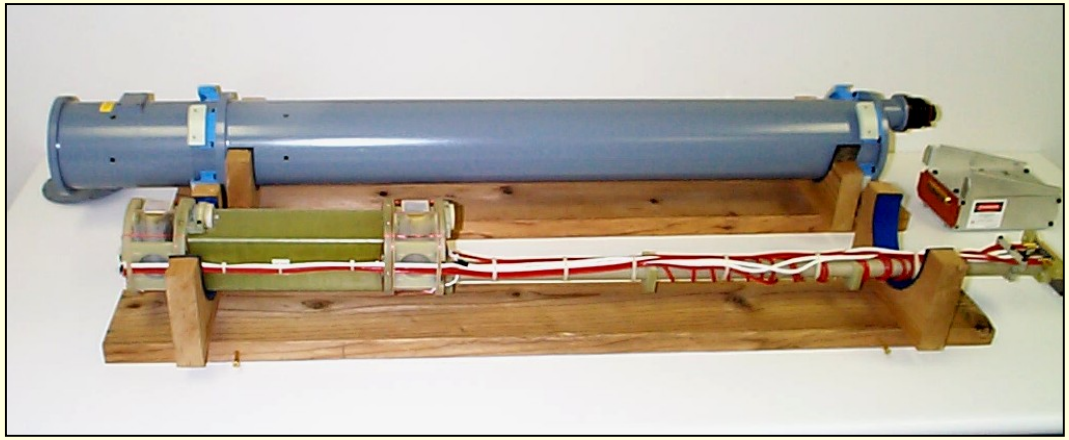
- **Provides 3D voxel imaging: along-track (SAS), cross-track (real aperture on wings), and vertical direction (pulse compression)**



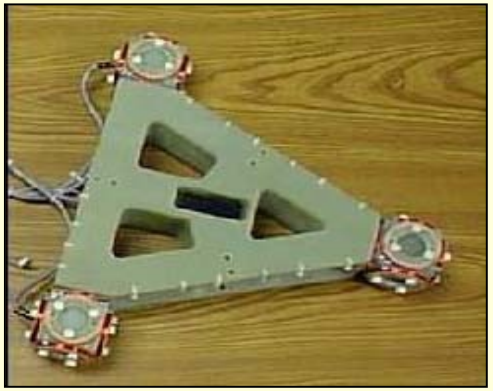


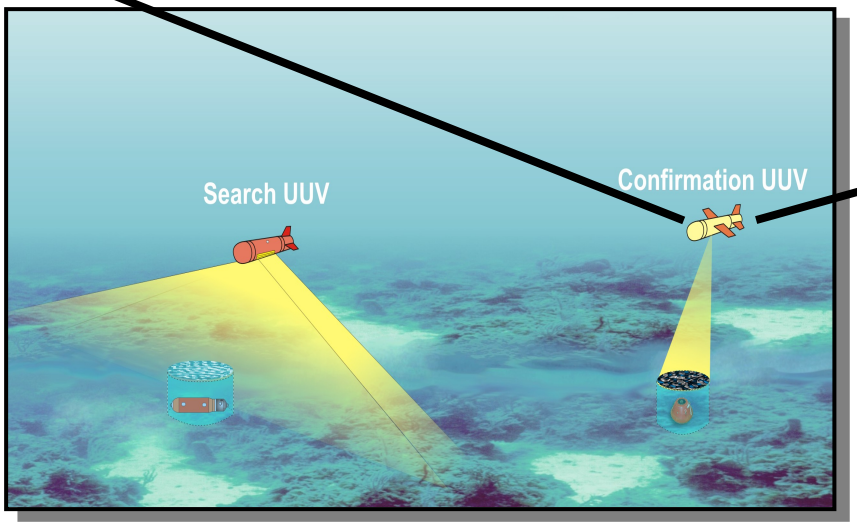
Magnetic Sensors

Laser-Pumped He4
Scalar
Gradiometer (LSG)
(Polatomic)



Real Time Tracking
Gradiometer (RTG)
(Quantum Magnetics)



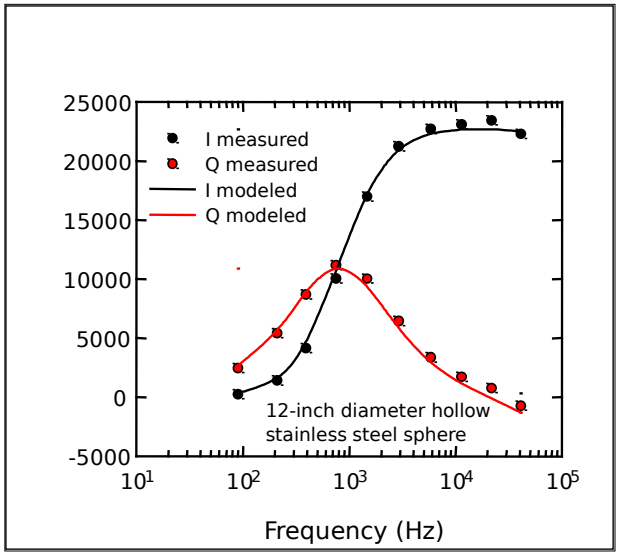


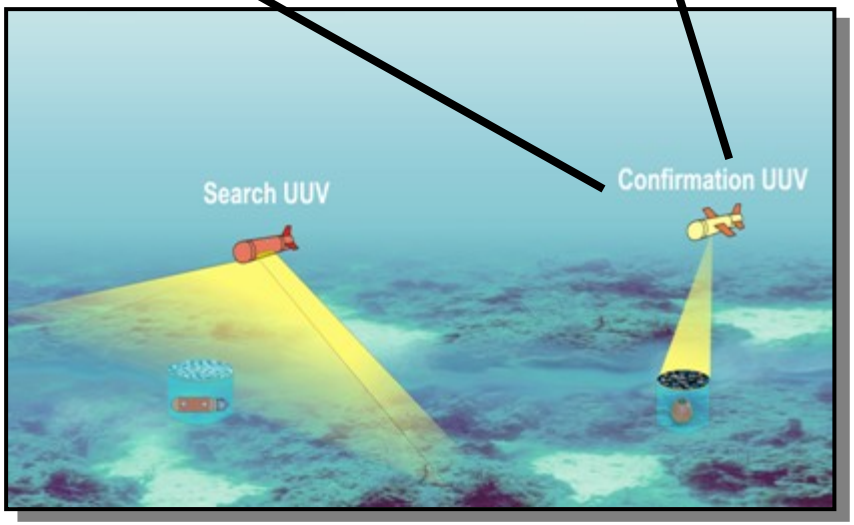
- **Real-time multi-target localization and magnetic moment determination**
- **Vehicle noise compensation schemes achieve low UUV magnetic noise floors (10 picotesla/m)**

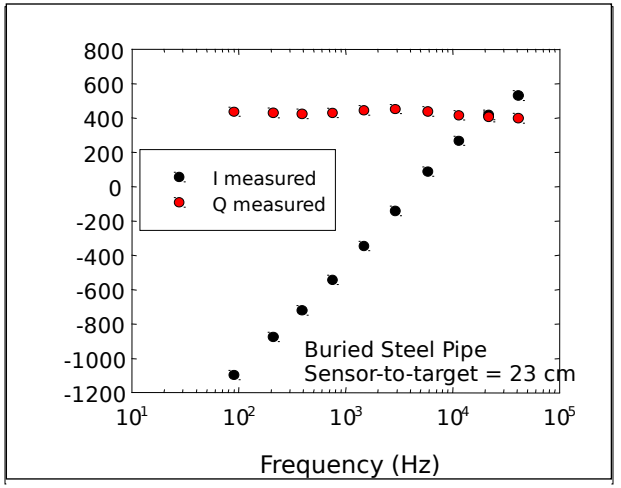
Active Electro-magnetic sors

GEM-3 Active EM Sensor
And UW Electronics
(Geophex)

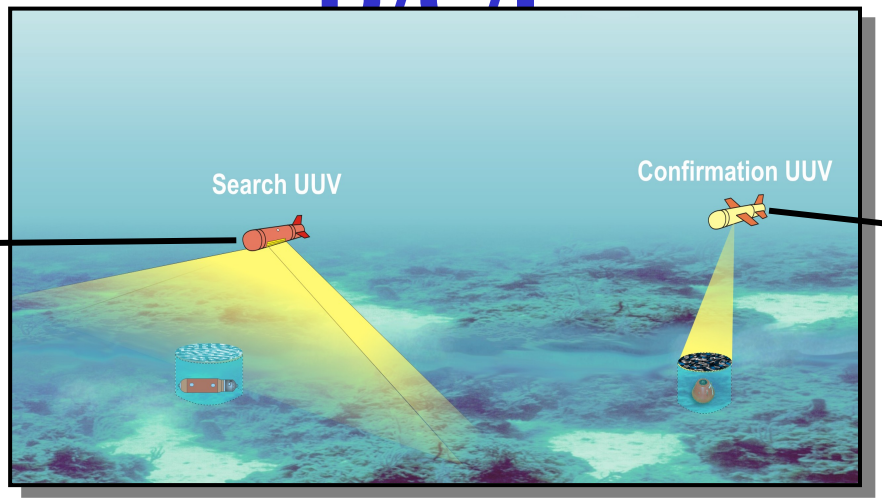
Unique In-Phase/Quadrature "Fingerprint"
Characterizes Detected Target







Automated Real-Time Mine D/C/I



SAS Data for Automated Detection and Classification

ID Sensor Suite Data for Automated Identification

Detection:
Locatize object in data

Feature Extraction:
- Shape
- Acoustic Color
- Resonance

Classification:
- Pattern Recognition Methodologies

In-situ Environmental Data

Sensor Modeling and Simulation

ID Initiation:
Localize object in data

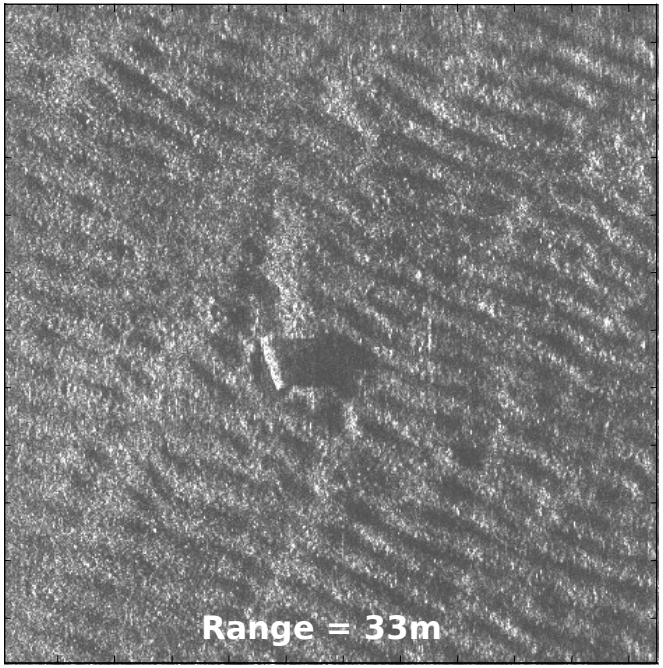
ID Feature Extraction:
- Acoustic
- Active E&M
- Magnetics
- Electro-Optics

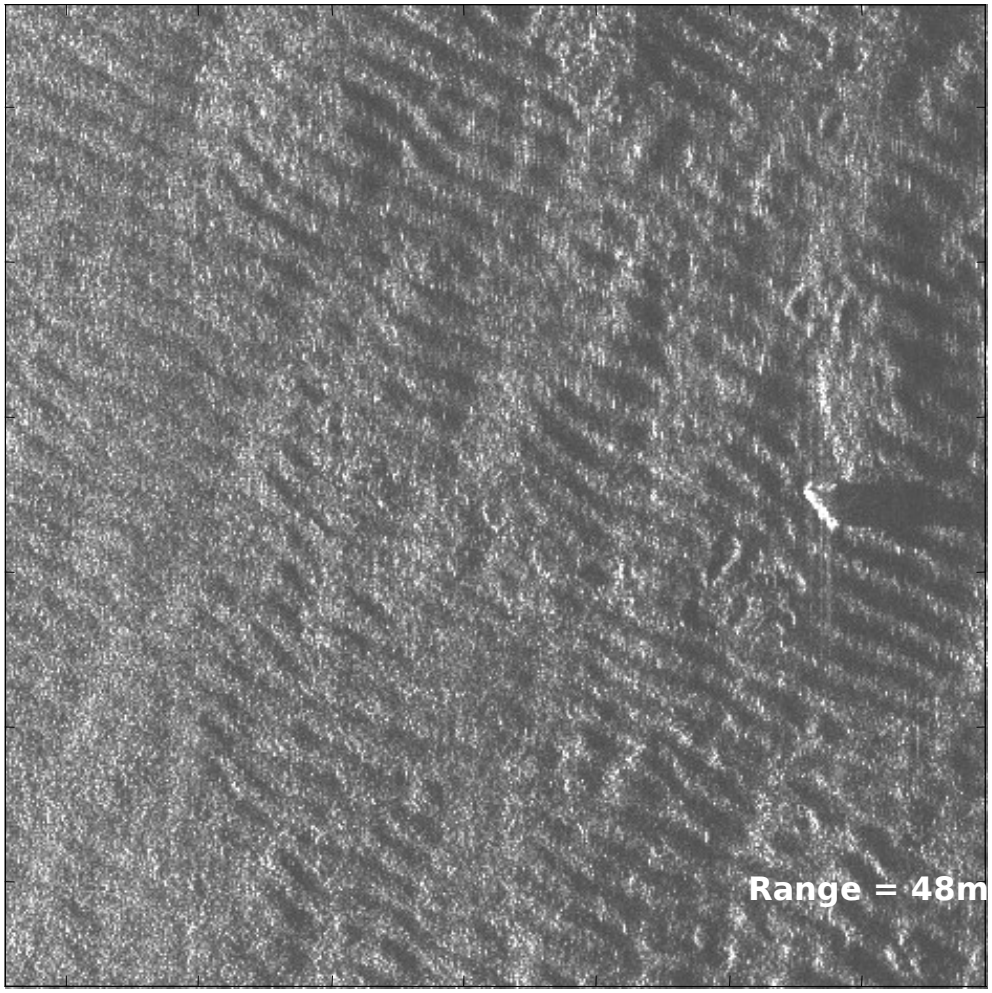
Identification:
- Sensor Fusion
- Pattern Recognition Methodologies

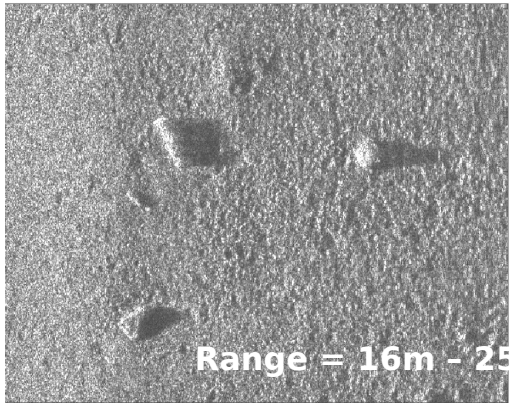
Acoustic Classification of Mines

- Imaging
- Acoustic Color

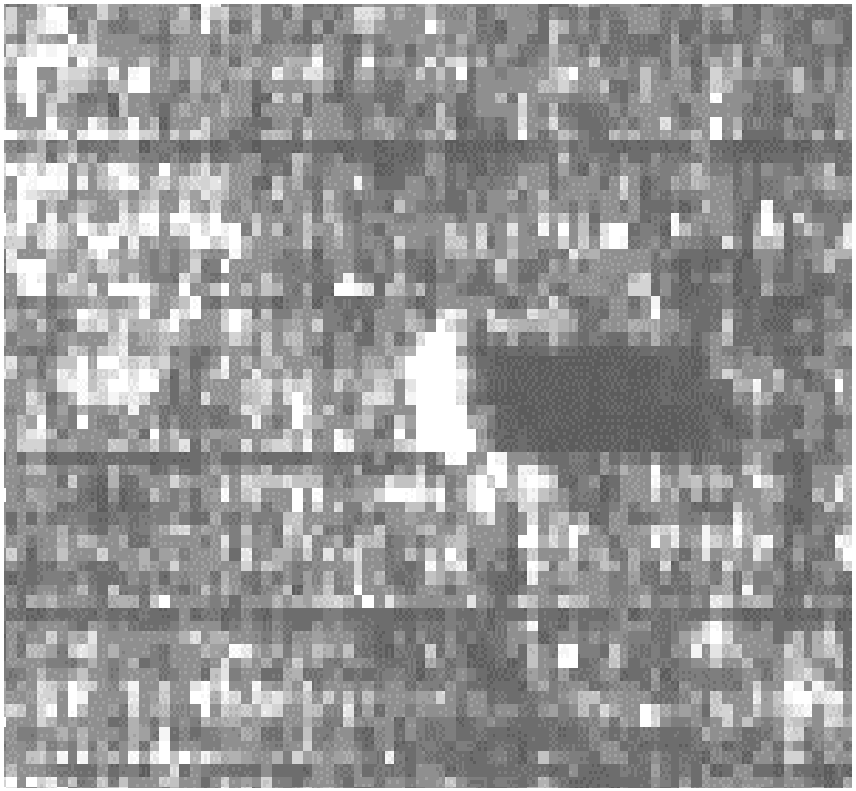
Sample 1” SAS Images

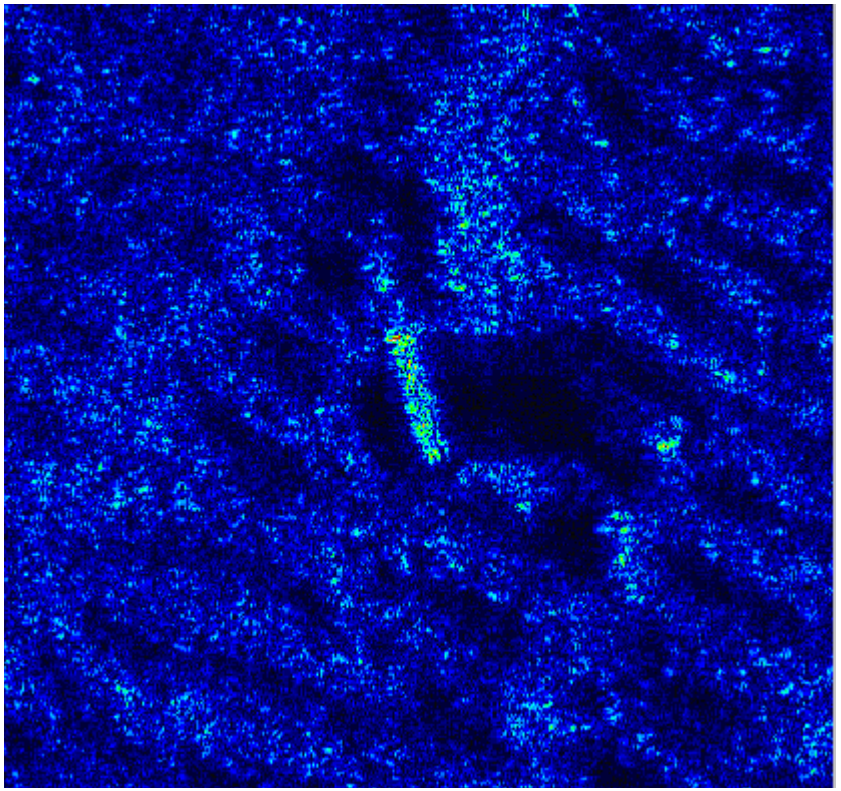






Sample 6” RAS and 1” SAS Images (same target, 17 months apart)

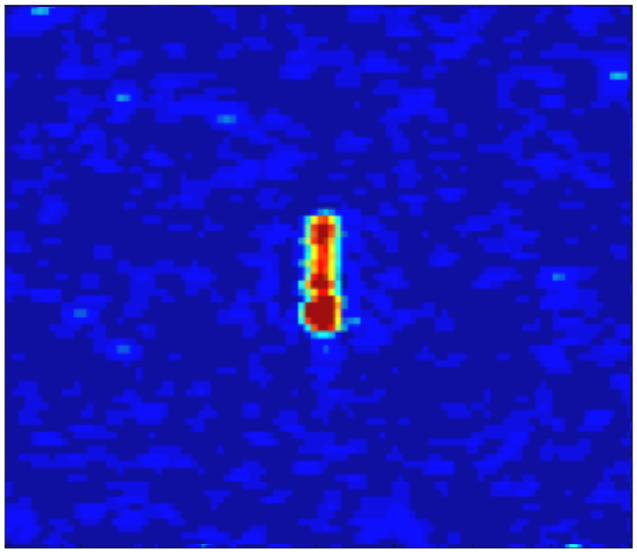




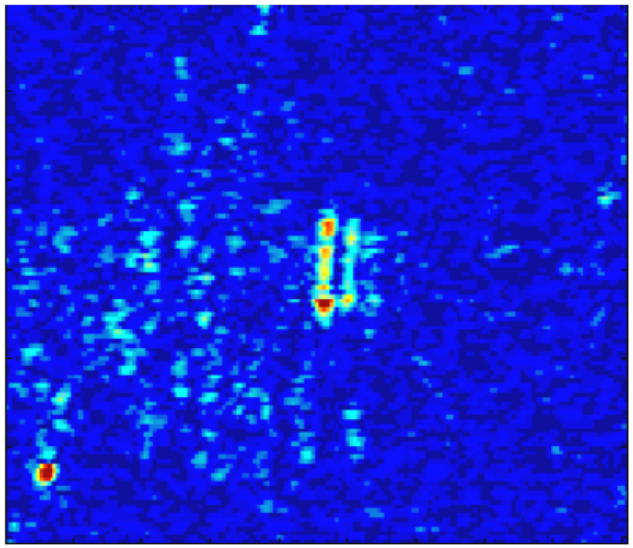
Sample 3” SAS Images (Buried Mines from SAX99)

20 kHz SAS
Sandy Bottom / Water Depth 18.3 meters
Sonar Altitude - 4 meters

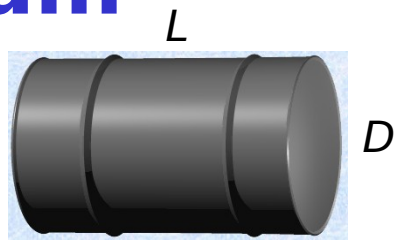
15 cm buried mine
25.6 m Range
30 dB measured SNR



50 cm buried mine
50.9 m Range
20 dB measured SNR



Oil Drum Acoustic Color Diagram



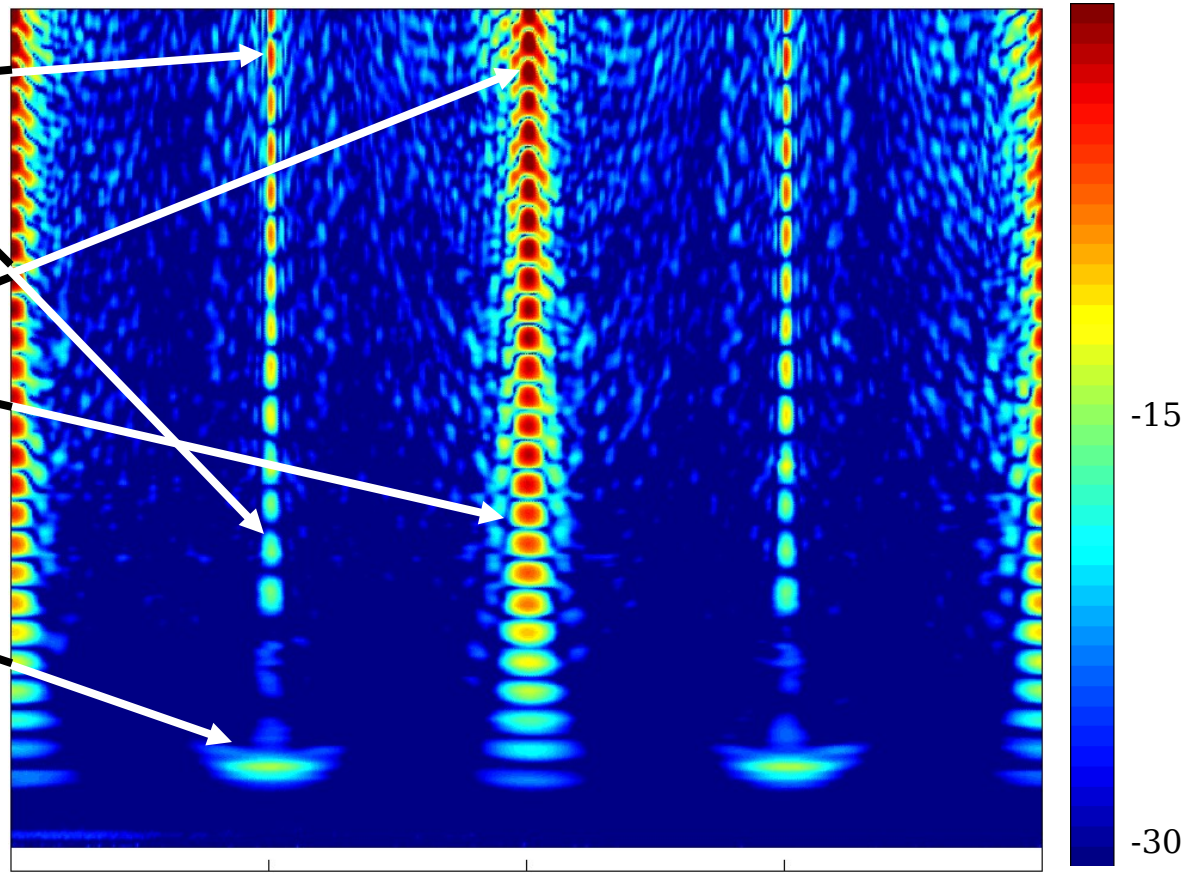
Geometrical interference pattern:

$\Delta f = c/2D \sim 1.3kHz$

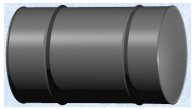
Geometrical interference pattern:

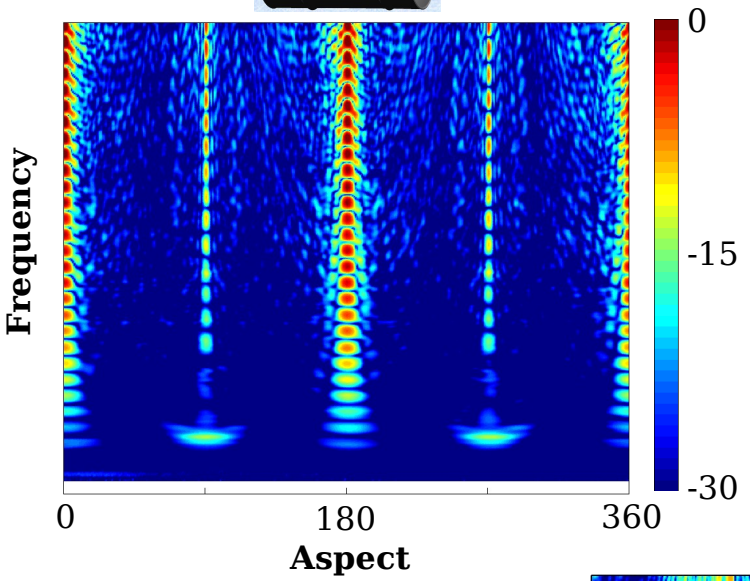
$\Delta f = c/2L \sim 0.87kHz$

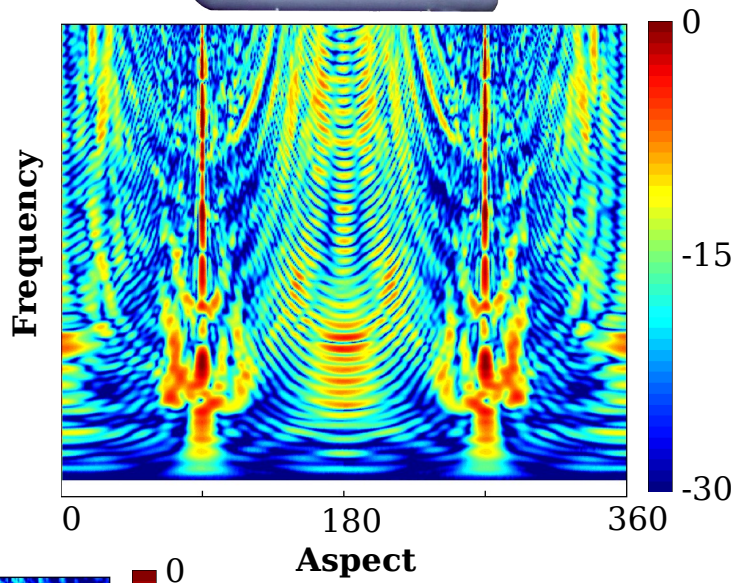
Resonance

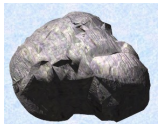


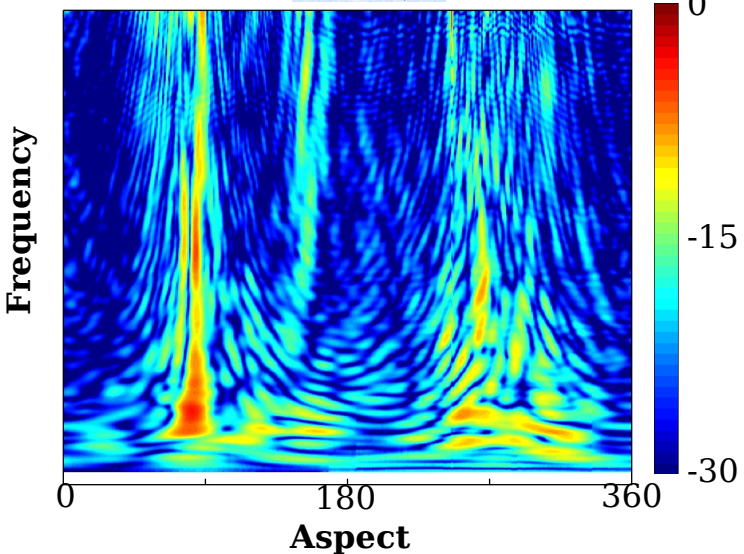
Acoustic Color Diagrams







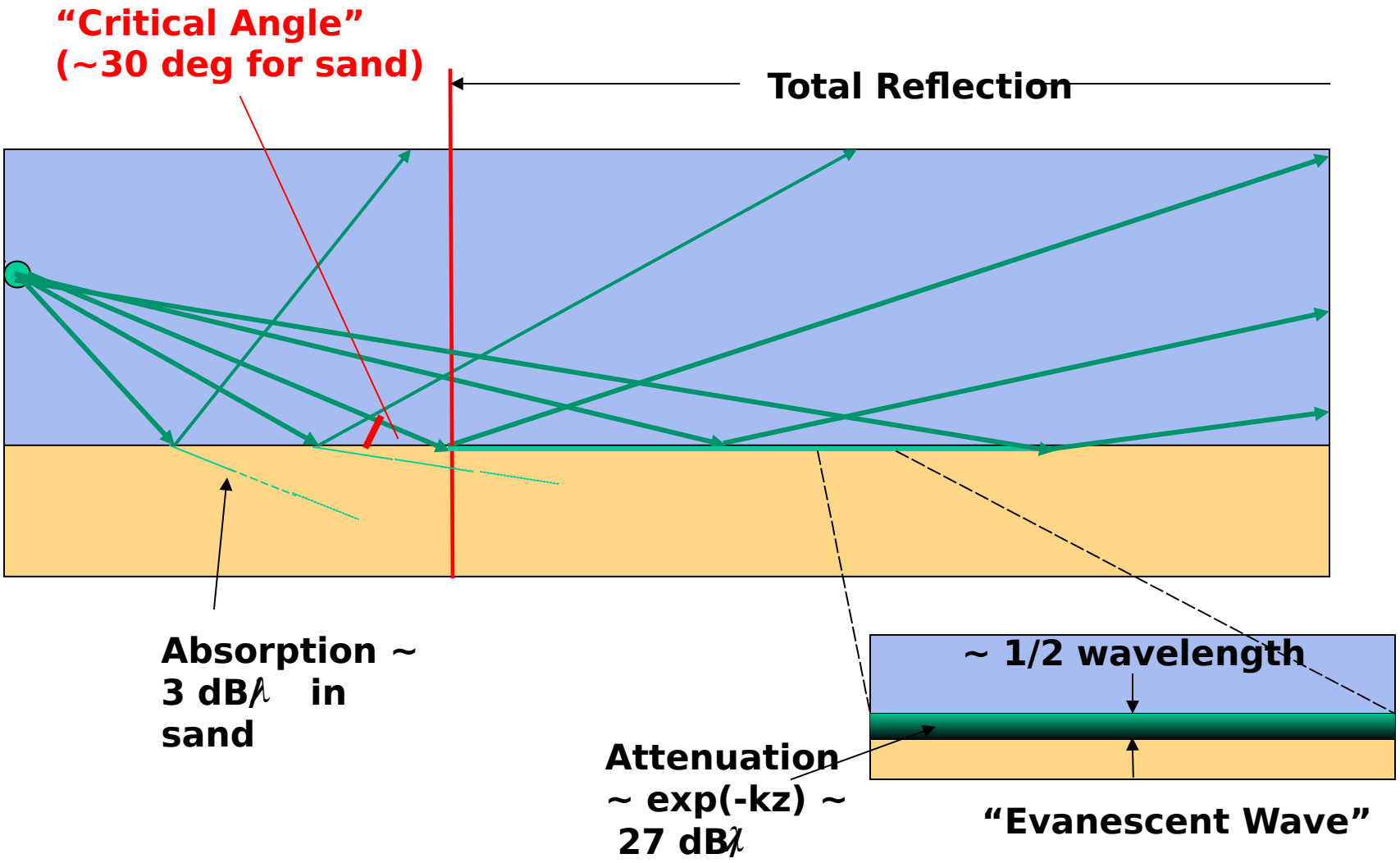




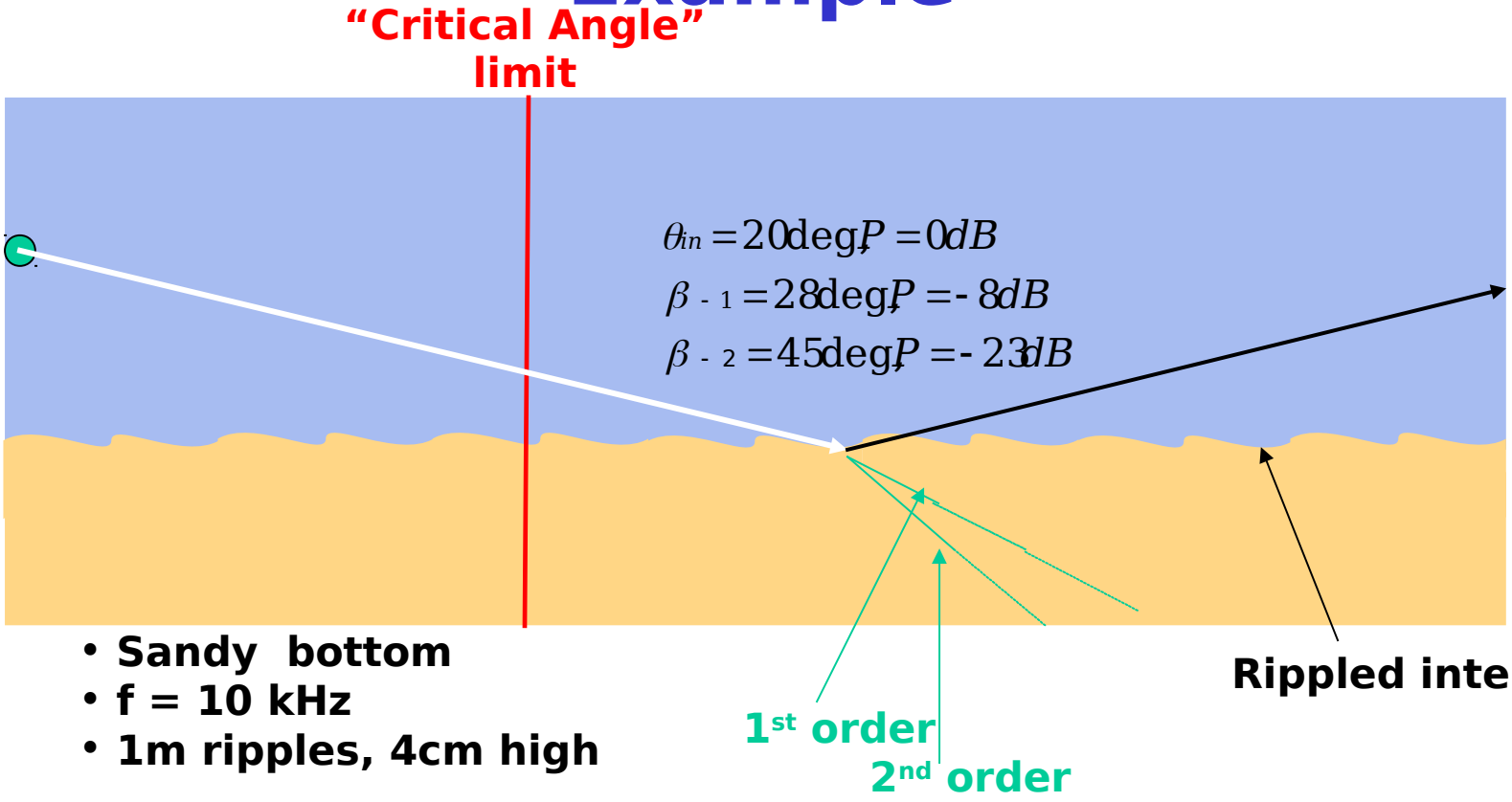
The Physical Acoustics of Buried Mine Hunting

- The two-fluid model
- Bragg scattering off of sand ripples

“Two-fluid Model” for Sound Propagation



Extra Penetration from Sand Ripple Bragg Diffraction: Example

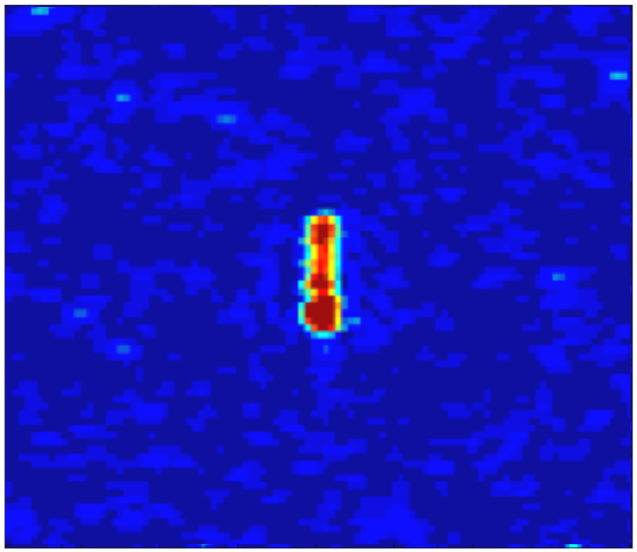


- Sandy bottom
- f = 10 kHz
- 1m ripples, 4cm high

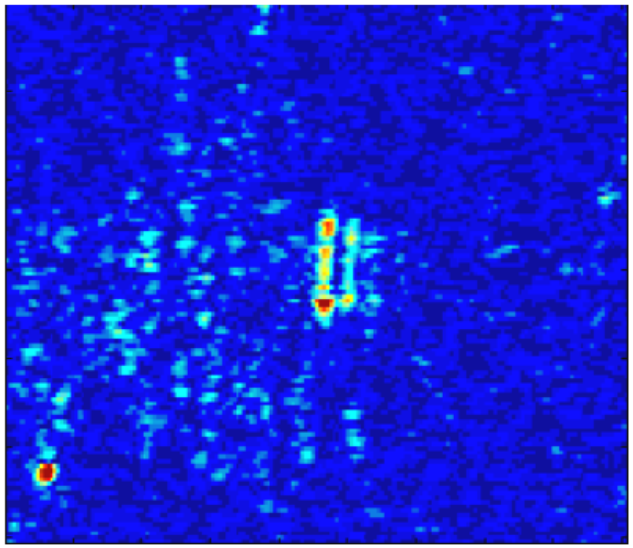
Apparent range separation to target buried a depth d: ~ .18d

Sediment Acoustics Experiment SAX99

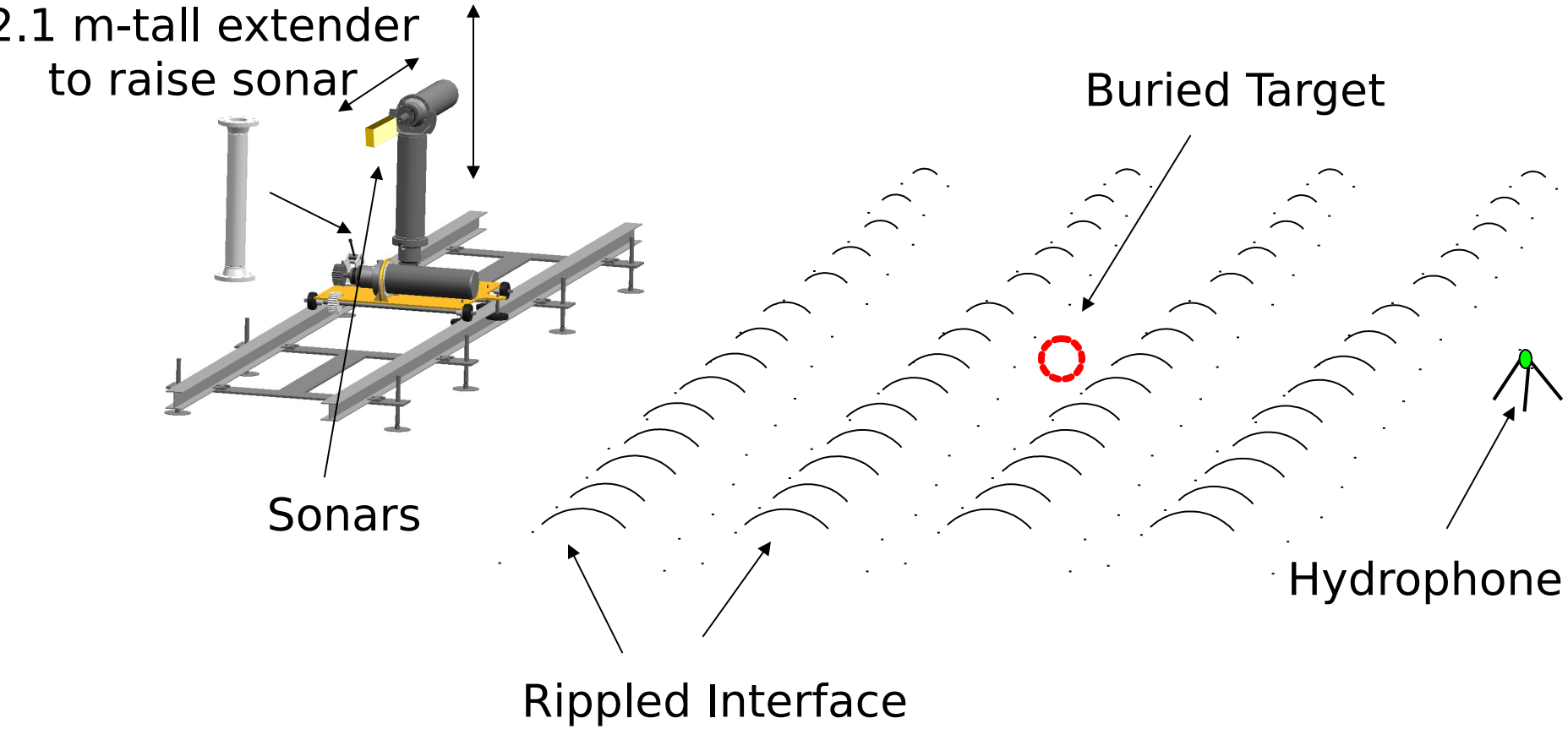
- Mine artificially buried 2 wavelengths deep(l) in rippled



- Mine artificially buried 7 wavelengths deep(l) in rippled

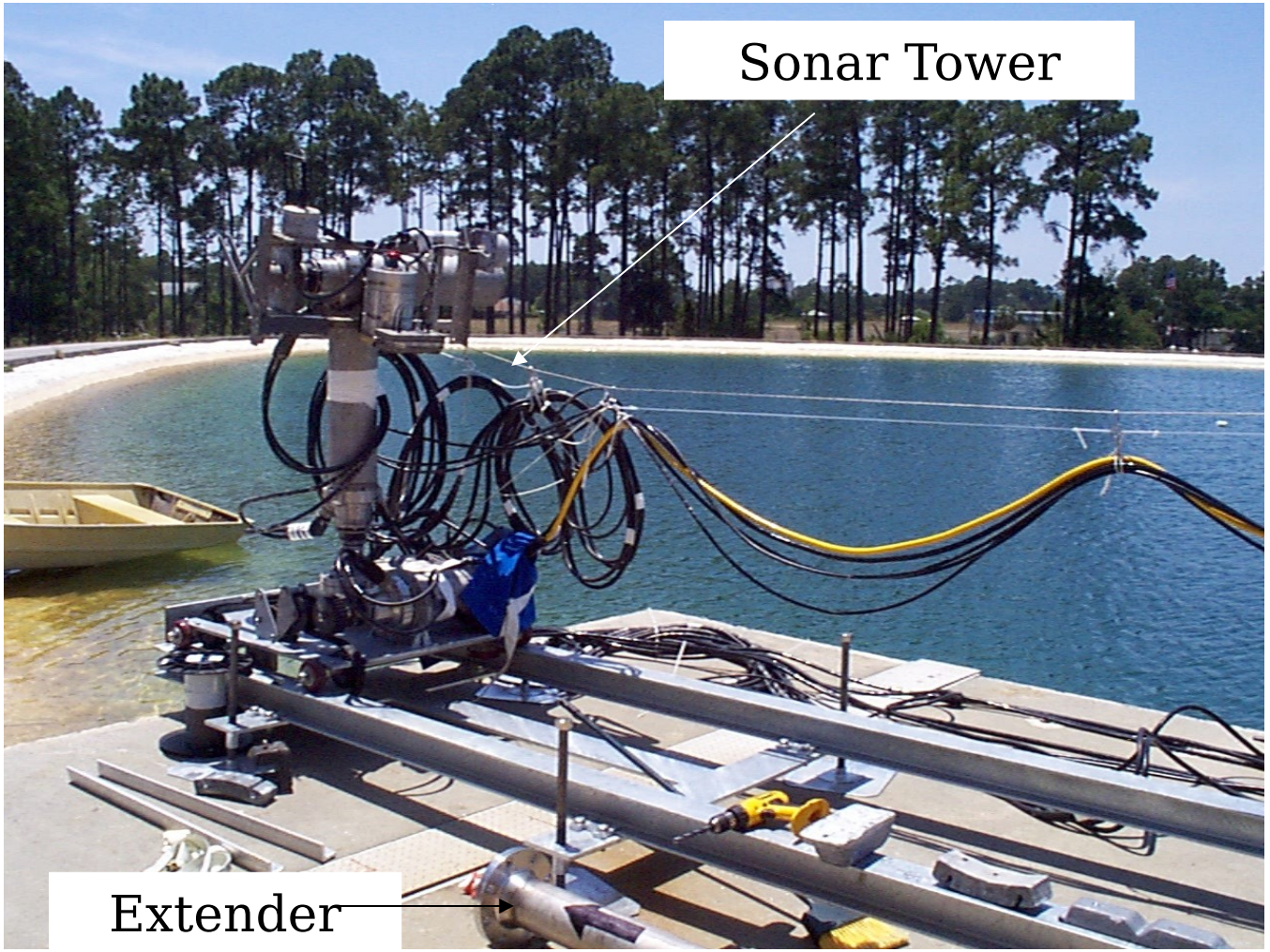


Target Field



- Target field geometry and sonar heights (with/without extender) permit grazing angles of 20° and 10°

Rail System

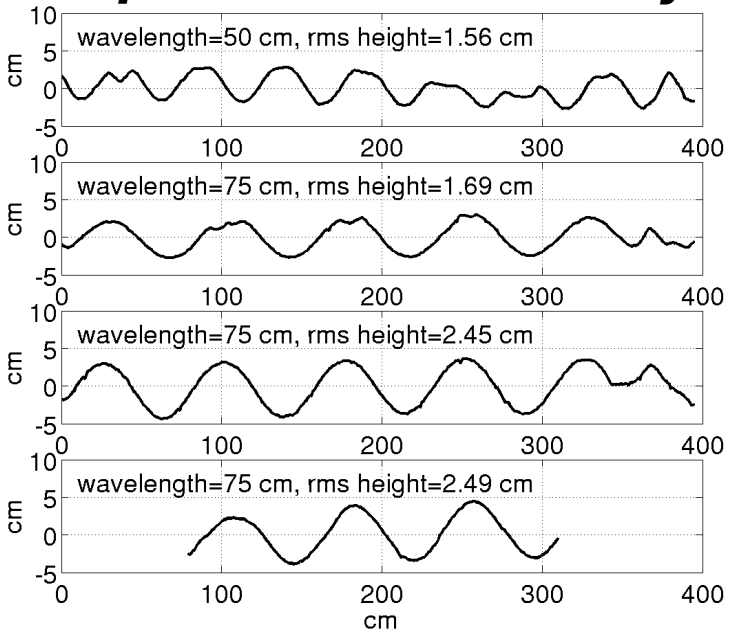


Bottom Profile Formation

Photo of sand scraper

Photo of APL/UW's IMP2

Bottom profiles measured by IMP2



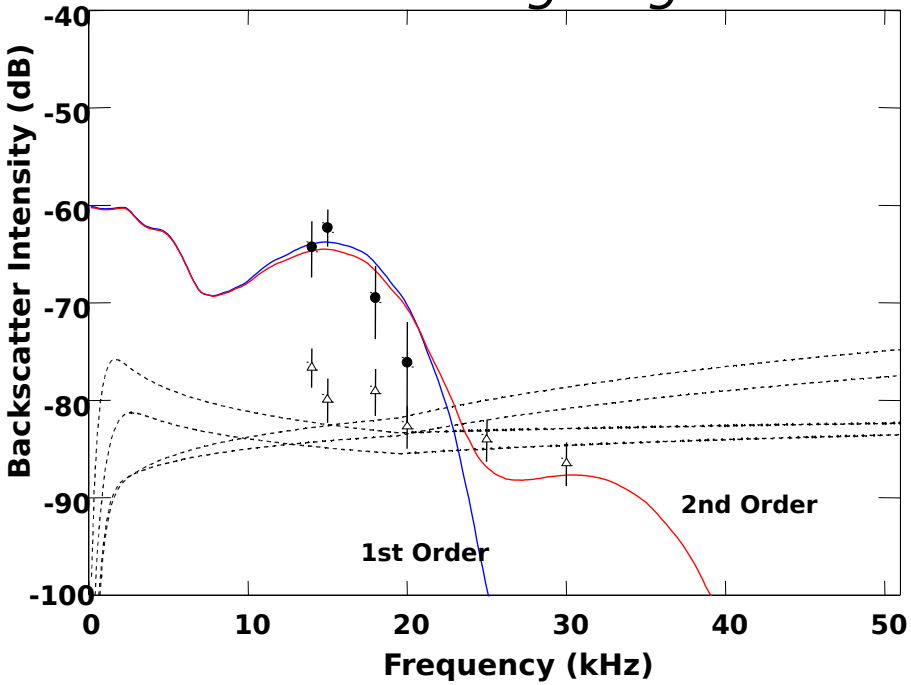
Ripple wavelength / RMS height

Designed	***Measured***
50 cm / 1.8 cm	50 cm / 1.6 cm
75 cm / 1.8 cm	75 cm / 1.7 cm
75 cm / 2.7 cm	75 cm / 2.5 cm
75 cm / 2.7 cm	75 cm / 2.5 cm

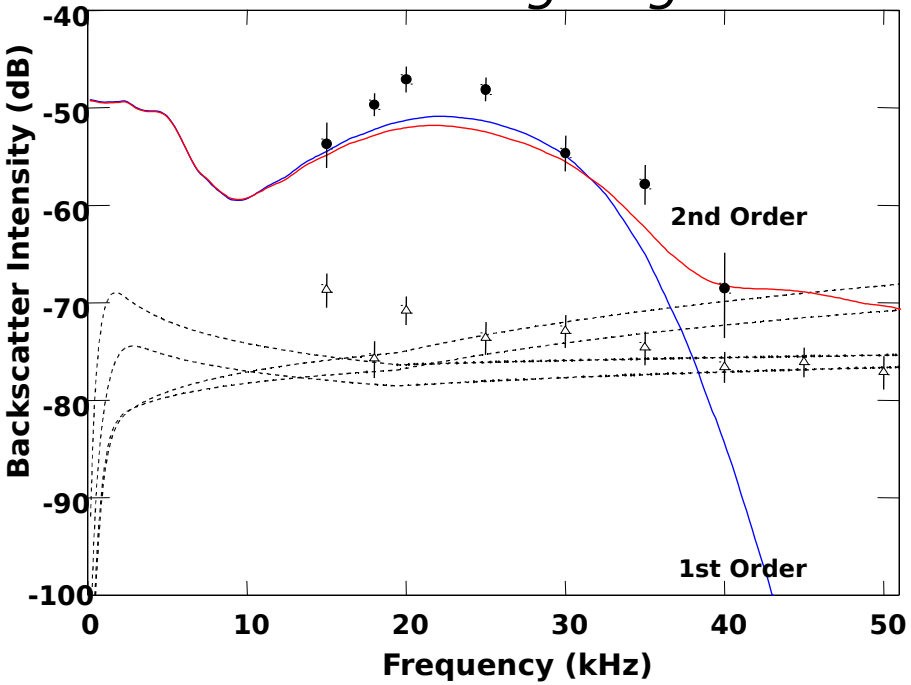
Model-Data Comparison of Returns from Buried Sphere

Ripple wavelength = 75 cm, RMS roughness = 1.7 cm
Burial depth = 5 cm under peak

10° Grazing Angle



20° Grazing Angle



Data: ● Sphere ▵ Bottom Reverberation

Remaining Physical Acoustics Problems for Buried Mine Hunting

- More environmental modeling and target classification challenges are sure to arise with more at-sea experience
- Little experience to date with mines buried in anything but sand